CHAPTER 5

ENVIRONMENTAL DATA COLLECTION AND ANALYSIS

5-1. General Considerations. In the process of planning and designing deep-draft navigation projects, assessment of potential environmental impacts must be made. This assessment is done through very detailed and site-specific data collection and evaluation efforts. However, there are basic requirements which are common to all data collection programs. This chapter outlines the general aspects to be considered when undertaking an environmental data collection program.

a. Problem Identification. Before objectives for a data collection effort are set, the problem to be addressed must be clearly identified. The general (and sometimes specific) nature of the problem may be ascertained from a variety of sources. These include EIS's, General Design Memorandums (GDM's), consent decrees, statutes, regulations, and interagency agreements. When a problem is identified, the initial step is to determine if it is amenable to analysis. Two determinations are involved in this process: first, if the means to obtain and/or analyze data exist (if not, the problem obviously cannot be investigated); and second, the cost and length of time required to obtain and analyze the data.

b. Setting Objectives.

(1) Need for objectives. The most essential part of an environmental data collection and analysis effort is the establishment of clear and concise objectives. If this is not done, the net result is often either an inability to solve the problem for which the data were generated, or a mass of data that defies rational analysis. Without good objectives, any data collection/analysis effort faces a high probability of failure.

(2) Nature of objectives. A well-written objective helps define specific actions or activities to address when a specific aspect of the issue is being investigated. It places bounds on the work to be done, excluding nonapplicable or unnecessary efforts. Wording of an objective should be clear, unambiguous, concise, and simple. An objective must be realistic and therefore attainable, oriented in a positive direction with no unproductive branching, and measurable to allow evaluation of progress and results.

c. Experimental/Study Design. When the nature of the data to be collected has been determined, attention is then directed to design of the experiment or study. The design is used to determine how the objectives will be met and includes decisions on parameter and variable selection, data collection methods, study milestones, resource allocation, and necessary reports. Use of CPM (Critical Path Method) logic networks is often helpful in outlining work to be accomplished and the sequence. The depth and detail of study should be comparable to other study elements in the current stage of planning or engineering, and consistent with the overall project scope.

d. Type of Data. There are two basic kinds of data: qualitative and quantitative. The former are subjective and nonnumerical, while the latter are objective and numerical. A qualitative approach to data collection may be called for if only descriptive data are required, the study is preliminary in nature, quality of previous data is poor, or a short suspense has been set. A quantitative approach is preferable because it can be expressed as a testable hypothesis. It is often useful to express the hypothesis as a question, for example, "Will (has) the project increase(d) (decrease(d)) some variable?" The objective of data collection then essentially becomes the verification or rejection of a hypothesis.

e. Documentation. Documentation of study/experiment findings is critical to the future use of the environmental data collected. Reporting requirements should be incorporated into the experimental design, taking into consideration the report format to be used. A common format used in reports of experimental data is given below:

(1) Introduction. This portion should contain background information and state the nature of the problem and how specific objectives will lead to resolving the problem.

(2) Materials and methods. This portion should consist of detailed field and laboratory procedures, place, time, number of samples to be taken, and methods to be used to analyze the data (test the hypothesis).

(3) Results. Measurements of variables and results of hypothesis testing should be given here. If extensive data are obtained, summary values should be given in this section with actual measurements provided as an appendix, on microfiche or on computer tape.

(4) Discussion. The significance of the results to meeting the study objectives should be set forth, together with qualifications and/or explanations.

(5) Conclusion. If the first four sections of the documentation are properly executed, one of three conclusions is probable. The first is that no problem actually exists; if so, no additional action is required. The second possible conclusion is verification of the problem as stated in the introduction. In this case, an additional section (Recommendations) is needed in the report to suggest means of avoiding, reducing, ameliorating, or mitigating the problem. A third possible conclusion is that additional data collection is required to properly address the objective.

f. Summary. The collection of environmental data for Corps water resource projects consists of several distinct steps, as outlined in Figure 5-1. The first is problem identification; this leads to the definition of objectives, which preferably involve quantitative data amenable to statistical evaluation. Definition of objectives is followed by experiment/study design and collection, analysis, and evaluation of data. Finally, the conclusions are referenced to the objectives and, if needed, appropriate recommendations are given. Findings are reported or presented in an appropriate form.

5-2. Monitoring Program

a. Purpose. Monitoring refers generally to the repetitive collection of data to evaluate changes and trends. Monitoring includes the overall process

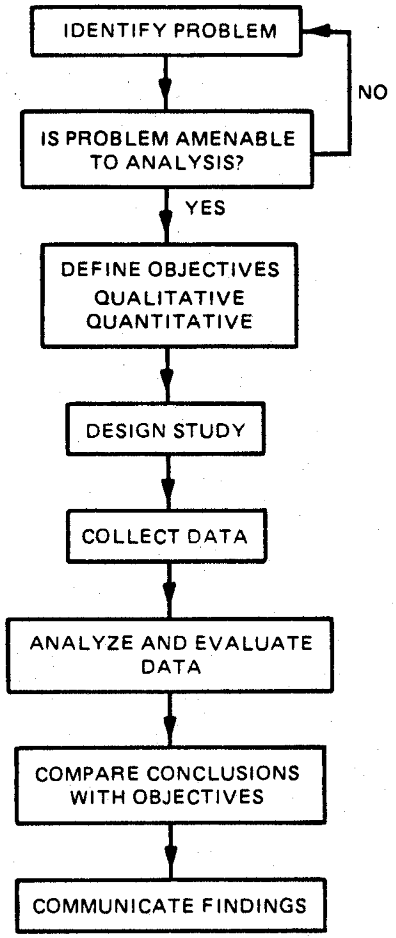


Figure 5-1. Major steps in conducting environmental studies

of data collection, analysis, and interpretation of immediate short-term or long-term changes associated with a project, and may be conducted over the life of the project. Environmental monitoring is usually conducted for one of two purposes, as described below.

(1) Monitoring activities are used to evaluate predictions from the planning phase and guide any necessary remedial work. These predictions are often found in the project EIS and relate to changes expected to result from the project. Before and after measurements are then compared to establish the accuracy of prediction (model). If a predicted change does not occur, or if an unexpected change does occur, this is an indication the predictor (model) is faulty. Although the monitored predictions cannot be redone for the existing project or activity being monitored, future predictive procedures can be improved.

(2) Monitoring is also used to determine if project operation meets water quality or other environmental standards. Coordination with other agencies or groups and examination of the EIS and legal requirements (consent

decrees, stipulations, rules and regulations, etc.) will usually reveal areas in which monitoring is desirable. Monitoring should be limited to parameters that provide information about issues of genuine concern.

b. Controls. Monitoring program design should provide for adequate controls. Data on baseline conditions serve as a temporal control, and reference site data serve as a spatial control.

(1) The baseline. A set of baseline data is required to measure change. By definition, baseline data must be collected prior to the construction, dredging, or other environmental disturbances of interest.

(2) Reference site. A reference site representative of without-project conditions at the project site should be included in the monitoring program if at all possible. The purpose of the reference site is to evaluate changes that occur through time but are not related to the project. Without a reference it is often very difficult to establish that observed changes are project related, and a question may remain as to whether natural variability or other perturbations were responsible for observed changes. In some cases it may be possible to control for other perturbations by establishing more than one reference site, as shown in Figure 5-2.

c. Quantitative Data. For scientifically and legally defensible conclusions, baseline monitoring and reference data should be quantitative and the experimental design such that hypotheses concerning change can be statistically evaluated. Quantitative data sufficient for application of statistical tests are often quite expensive, a fact which underlines the importance of careful selection of parameters for measurement.

d. Remedial Action. The monitoring program design should include consideration of potential remedial action. If a desirable change does not occur or if an undesirable change is detected, this information is of little worth unless a remedy is provided. Of course, should predicted change not occur or unexpected change be observed, it is an indication that the predictive procedure was faulty. In such a case, this can serve as a useful feedback mechanism to modify and improve the predictive procedure; this can avoid the repetition of error in the future.

e. Example. A simple hypothetical example will serve to illustrate the principles stated above. It was predicted that a Corps project would result in an increase of the numbers of frecklebelly madtom, an endangered fish species. This prediction was based upon knowledge of the environmental requirements of the frecklebelly madtom; the current (preproject) habitat conditions were marginal, and the project was expected to transform these conditions to a more favorable situation.

(1) Baseline data. Prior to construction, the project manager initiated studies to establish baseline conditions of those physical, chemical, and biological variables influencing the frecklebelly madtom and conducted detailed population estimates in the project area as well as in adjacent and very similar (reference) areas. These studies were conducted over a five-year period to take natural variability into account.

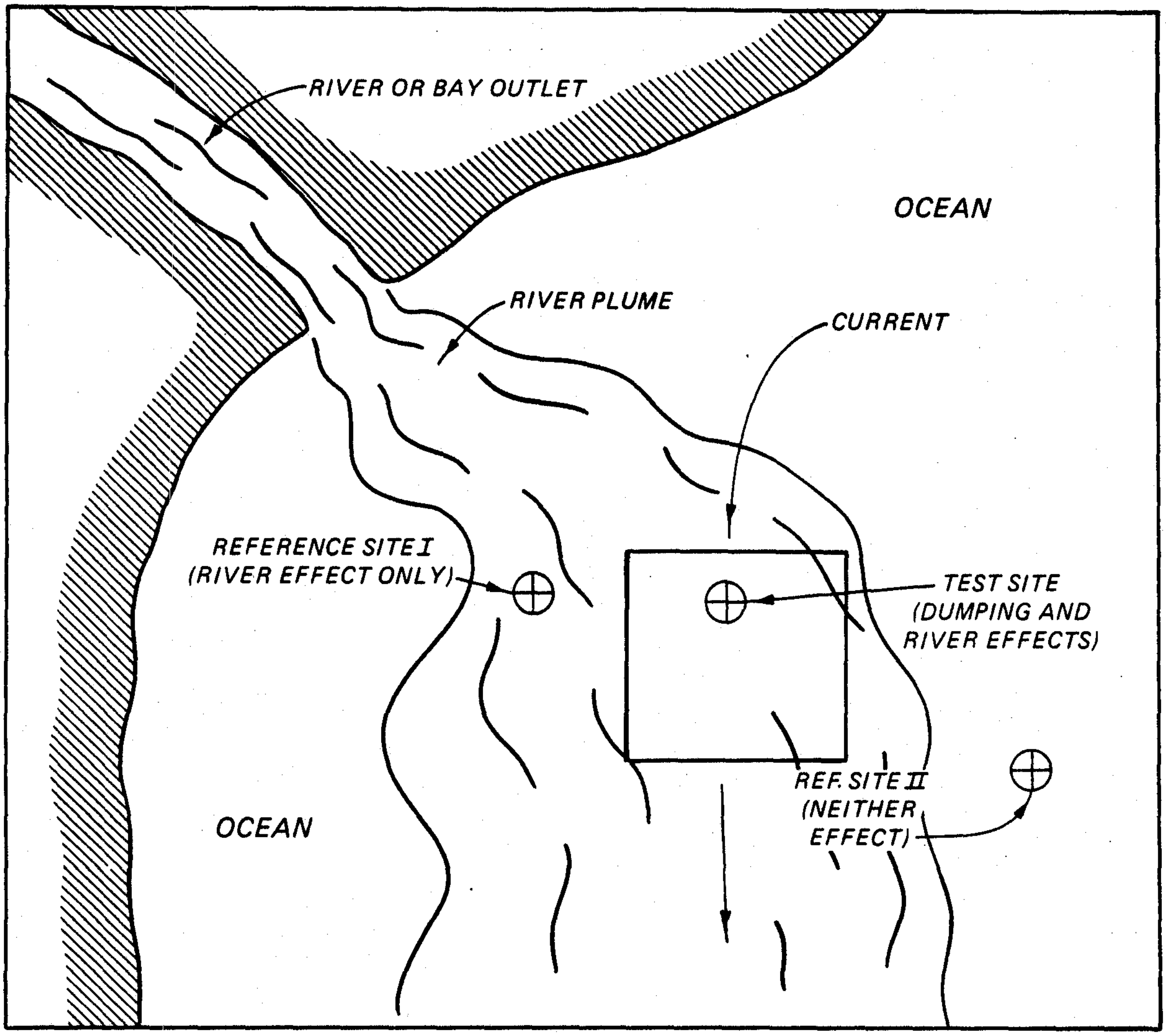


Figure 5-2. Diagram showing two reference sites and monitoring site for a case where a polluted river flows over a dredged material disposal site. Reference site I is control for the test site since the tested variable difference is the dumping. Reference site II is the control for the reference site where the test variable is the polluted riverflow in the ocean.

(2) Monitoring program. Upon project completion, the monitoring program began. Data were obtained for physical, chemical, and biological variables, and population estimates were made of the frecklebelly madtom in the project and reference area. After three years (once again to account for natural variability), it was found that the frecklebelly madtom population in the project area had doubled since construction, but there was no significant change in the reference area population.

(3) Analysis. As there was no change in the reference area population, it was concluded that the predicted change had occurred and had resulted from the project. If there had been a decrease of frecklebelly madtoms in the

project area, the cause of the decrease would have been evaluated by comparison with the reference. If frecklebelly madtom declined or vanished from both project and reference areas, it would indicate that factors other than the project were influencing the population. If populations decreased in the project area but remained stable in the reference area, it would indicate that the predictions were deficient or that the reference area was inappropriate.

5-3. Data Collection. This section provides general guidance necessary to plan an environmental monitoring program that will meet stated objectives of the experimental design. The most critical aspect of data collection is selecting proper parameters to sample and measure in order to answer or solve identified problems.

a. Primary Consideration. The quality of the information obtained through the sampling process is dependent upon: (1) collecting representative samples, (2) using appropriate sampling techniques, and (3) protecting the samples until they are analyzed (sample preservation). Other factors impacting on sampling process are time, costs, and equipment constraints, which will limit the amount of information that can be gathered. Under such conditions, careful tailoring of the monitoring program is required.

b. Quality Control. An effective quality control program must be an integral part of a project from the initial planning for field sampling, through completion of the activity. During the initial meeting, which should include coordination with laboratory and field personnel, the field crew should be made aware of the fact that chemical changes can occur following collection of samples; they should also know how to handle the samples to minimize or prevent these changes. At the same time, laboratory personnel should be reminded of their responsibility to complete the required analysis within the specified time period. A complete quality control program should emphasize sample handling techniques. This is necessary because the greatest potential for sample deterioration and/or contamination occurs during the preanalysis steps of sample collection, handling, preservation, and storage. These problems can be minimized by following prescribed sample handling techniques.

c. Representative Sampling. The purpose of collecting samples is to define physical/chemical characteristics of the project area environment. To do so requires that samples be taken from locations which are typical of ambient conditions found at the project site. Failure to obtain samples that are truly representative of a given location will result in inaccurate data and misinterpretations.

d. Sampling Site Selection and Location.

(1) General. The following factors should be involved in sampling site selection:

(a) Objectives of the study.

(b) Accessibility of the site by personnel and equipment.

(c) Flows (consider extremes of flow, duration, and velocity).

(d) Mixing.

(e) Source locations.

(f) Available personnel and facilities.

(g) Other physical characteristics.

(2) Sampling locations and parameters to be evaluated. The decision on sampling locations must consider point and nonpoint sources in the project area, and factors that could be critical to the parameter distribution pattern. Primary station locations will depend upon the specific site characteristics and the sampling objectives. Because of this, no firm guidance can be given on the number of sampling stations that should be established. Knowledge of point sources can provide a basis for selecting the parameters for which analyses should be completed. In addition, an evaluation of land use activities in the area can provide an indication of nonpoint contaminants and also contribute to the determination of parameters to be included in the analysis.

(3) References and controls. An additional factor that should be included in establishing a sampling program is the selection of a reference station and/or a control station. Data from a reference or control station are required for comparisons of before, during, and after project construction.

(4) Sampling guidance. The following general guidance is offered as an aid in establishing a biological/sediment sampling program.

(a) Sampling stations should be located downstream from major point sources in the project area. These sources may be selected based on specific constituents in the effluent or on the volume of the discharge. It is usually possible to define these sources based on a knowledge of the activity in the area or a review of historical data for the site.

(b) Additional sampling stations should be located in areas of low hydrologic activity or energy. The reason for sampling these locations is that the lower energy favors the settling of smaller sized suspended particulate matter. This material, due to the greater surface area per unit weight of particulate matter, tends to have higher concentrations of associated chemical contaminants. Suggested locations are:

1 On the outside bend of channels.

2 In backwater areas or side channels.

3 In areas of heavy shoaling or deposition.

However, sampling in these areas may produce sample results that are biased high, and may not be representative of the concentrations in the project area. That is, if primary sampling locations are located in these areas, the concentrations would be expected to be higher than at a more remote project site, and caution should be exercised when trying to extrapolate conclusions from these samples to the entire project area.

(c) Sampling stations should be located in other areas not described in the two categories above. As mentioned previously, sampling below major point sources and in areas of settling to define the maximum concentration that will be found in the sediments of the project area may produce nonrepresentative samples. Therefore, in order to provide a representative idea of contaminant concentration and distribution, samples should also be collected at random locations removed or upstream from major point sources and in areas of higher hydraulic energy (i.e., inside bends of channels). In this way, data obtained from sample analysis will provide information on the range of sediment properties and compositions that can be expected, and the entire set of resultant data will be more representative of the project area. The number of sampling stations located in such areas should be equivalent to the number of stations in categories 1 and 2 of subparagraph (b) above.

(d) If a control area or a former disposal site is to be sampled for comparative purposes, multiple stations should be sampled. Sample composition from these areas will also be variable and cannot be defined based on a single sample.

e. Number of Samples. Guidance in this section is limited to general concepts. First, the greater the number of samples collected, the better the conditions will be defined. Second, the mean of a series of replicated measurements is generally less variable than a series of individual measurements. Third, statistics generally require two characteristics, usually mean and standard deviation, because single measurements are inadequate to describe a sample. Fourth, the necessary number of samples is proportional to the source heterogeneity.

(1) Consideration of the above factors suggests that replicate samples should be collected at each location and that a minimum of three replicates are required to calculate standard deviations. Beyond the replication at a single point, the factors listed above do not limit the number of samples needed since it depends on site-specific heterogeneity (distribution pattern) and the desired level of source definition (degree of precision). The total number of samples is controlled by the type of sampling pattern selected (random, cluster, uniform) (see Figure 5-3). (Additional information regarding number of samples is given in Elliott (1977), Green (1979), and Snedecor and Cochran (1967).)

(2) A rapid method for determining the number of samples necessary when investigating a biological population is to calculate the cumulative mean of a few samples obtained in a pilot survey. A cumulative mean (or running average) consists of taking the average of samples 1 and 2; then of samples 1, 2, and 3 (first, second, and third, etc.); then of samples 1, 2, 3, and 4 (and so on), until all samples have been included. If the results are displayed (see Figure 5-4), the plot of mean values will stabilize as more and more samples are included. In populations with a random distribution (when the variability is fairly low), the mean stabilizes quickly (see Table 5-1). In the cluster distribution (Table 5-2), the variation is quite high and the total cumulative mean stabilizes slowly. In the example given in Table 5-1, the random distribution stabilizes at about 8 or 10 samples. In the cluster distribution pattern, the line never stops fluctuating, although as can be seen in Table 5-2, after about 15 samples the data begin to stabilize.

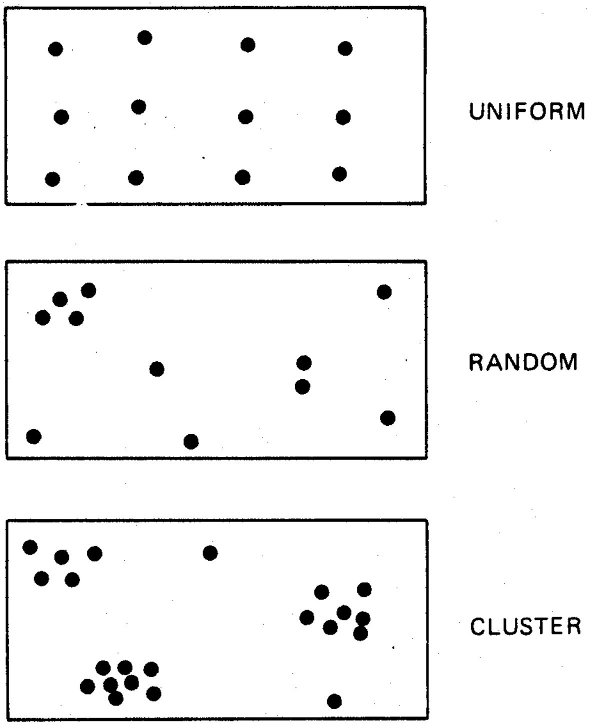


Figure 5-3. Three possible distribution patterns

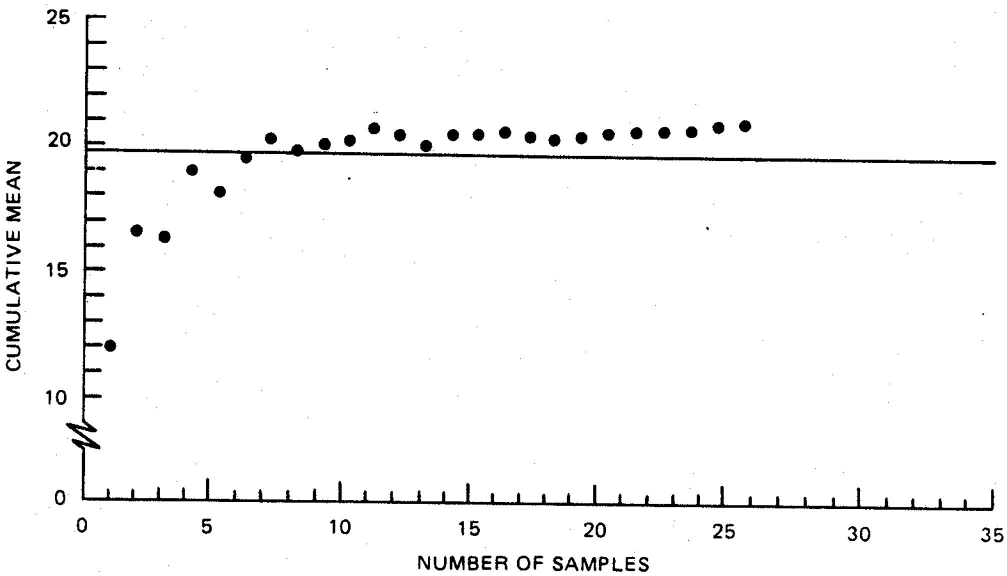
(3) A more sophisticated technique is described by Green (1979). A preliminary or pilot survey is taken from the population, and individual counts are made from each collection to calculate the sample mean and standard deviation. The formula then used is:

$$\bar{X} \pm t_{1(1/2)} = S/n^2$$

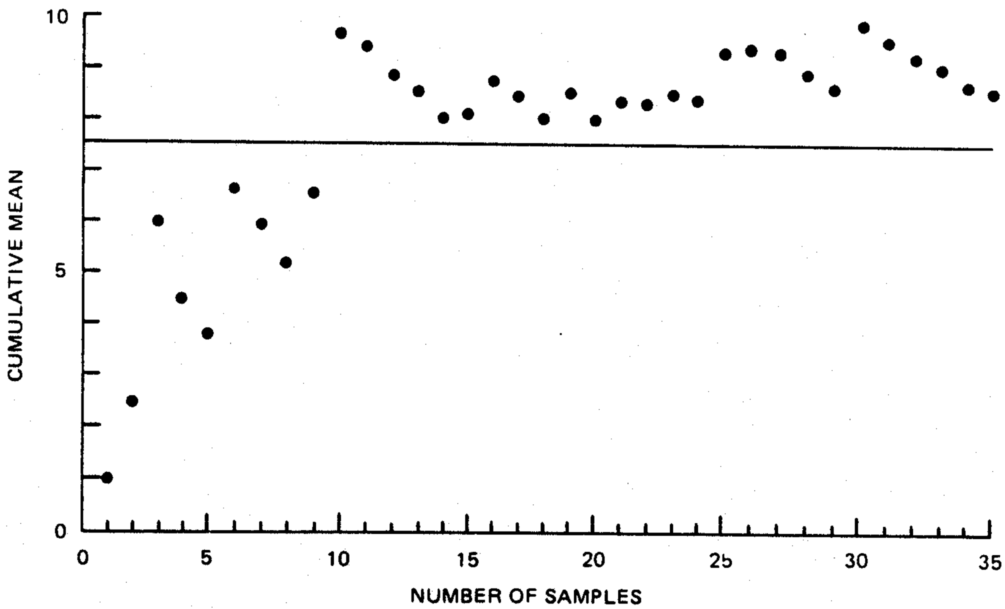
where $\bar{X}$ is the sample mean, t is the t statistic, n is the number of samples, and S is the standard deviation. In the following example, assume that an investigator wishes to estimate the mean density of a species in a population within 10 percent of the actual number and with a 1-in-20 chance of being wrong. The t value is unknown and is a function of n-1 degrees of freedom; however, for fairly large sample sizes, t is a weak function of n and is approximately 2.

(4) An additional factor which will limit the number of samples is financial resources. In this case, the number of samples upon which analyses can be performed is determined by the ratio of available dollars and cost per sample:

$$\text{Numbers of samples} = \frac{\text{Dollars available}}{\text{Cost per sample}}$$



a. Random



b. Cluster

Figure 5-4. Cumulative means calculated for random and cluster distributions

Table 5-1. Cumulative Means From a Series of Randomly Collected Samples Taken From a Population with Random Distribution

Observation	No. of Individuals (X)	Sample Mean (X)
1	12	12.0
2	21	16.5
3	16	16.3
4	27	19.0
5	15	18.2
6	27	19.6
7	25	20.4
8	15	19.8
9	25	20.3
10	21	20.4
11	25	20.8
12	19	20.6
13	15	20.2
14	25	20.6
15	22	20.6
16	23	20.8
17	19	20.7
18	20	20.6
19	24	20.8
20	23	20.9
21	23	21.0
22	21	21.0
23	22	21.1
24	27	21.3
25	22	21.4
Total	534	--
Standard deviation	4.16	--
Standard error of the mean	19.48	--

Table 5-2. Cumulative Means From a Series of Randomly Collected Samples Taken From a Population with Cluster Distribution

Observation	No. of Individuals (X)	Sample Mean (X)
1	1	1.0
2	4	2.5
3	13	6.0
4	0	4.5
5	1	3.8
6	21	6.6
7	1	5.9
8	1	5.2
9	18	6.6
10	37	9.7
11	6	9.4
12	4	8.9
13	5	8.6
14	1	8.1
15	10	8.2
16	18	8.8
17	4	8.5
18	1	8.1
19	17	8.6
20	0	8.1
21	14	8.4
22	5	8.3
23	16	8.6
24	6	8.5
25	31	9.4
26	11	9.5
27	8	9.4
28	0	9.1
29	2	8.8
30	44	10.0
31	0	9.7
32	2	9.4
33	1	9.2
34	0	8.9
35	6	8.8
Total	309	--
Standard deviation	10.9	--
Standard error of the mean	123.5	--

This approach will provide one method of estimating the number of samples that can be collected and analyzed. However, should the calculated number of samples not be sufficient to establish an adequate sampling program (i.e., number of samples insufficient to allow triplicate sampling at all locations indicated in paragraph 5-3d), one of the following trade-offs will to be accepted:*

(a) Reduce the replicate sampling at each station. This will allow the chemical distribution within the project area to be determined, but variability at a single sampling station location cannot be calculated.

(b) Maintain replicate sampling but reduce the number of sampling locations. This will result in the project area being less well defined, but sampling variability can be calculated.

(c) Increase the financial resources available for sample analysis. This will increase the number of samples that can be collected and analyzed.

(5) It is suggested that consideration be given to collecting samples (locations and numbers) in excess of that determined by the above process. Depending upon the parameters being evaluated, the samples do not have to be scheduled for analysis and may even be discarded later without analysis. Should sample analysis indicate some sort of abnormal results, it is easier to analyze additional samples already on hand rather than to remobilize a field crew. Also, the additional variable of different sampling times is avoided with this approach.

f. Frequency of Sampling. Frequency of sampling will depend on the available resources and the size of the project. In addition, seasonal fluctuations of sediment concentrations may be critical, or a single sampling prior to a dredging or filling operation may be sufficient for a new-work project. A sampling frequency of once per year would probably also be sufficient for an annual maintenance project, unless there is a reason to believe otherwise (i.e., some major change in point sources or basin hydrology).

g. Sampling Techniques Selection.

(1) Considerations. Sampling equipment should be selected based on reliability, efficiency, and contamination potential. Several types of sediment samplers are described in Table 5-3. Sediments are frequently stratified vertically as well as horizontally, and this source of variability should be considered when choosing a method of sampling (i.e., grab versus corer). A

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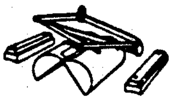
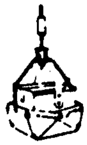
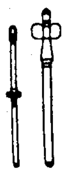
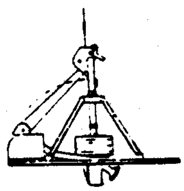
* The distinction between option (a) and option (b) should be based on project-specific goals. If option (a) is used (more stations, fewer replicated), the results will provide a better indication of distribution patterns in the project area (synoptic survey), but it will be difficult to compare individual stations. On the other hand, if option (b) is used (fewer stations, more replicates), the results will provide a better indication of variability at one location and comparison between sampling stations. However, the project area will be less well defined.

Table 5-3. Sediment Sampling Equipment

Sampler		Weight	Remarks
Peterson		39-93 lb	Samples 144-in.^{2} area to a depth of up to 12 in., depending on sediment texture.
Shipek		150 lb	Samples 64-in.^{2} area to a depth of approximately 4 in.
Ekman		9 lb	Suitable only for very soft sediments.
Ponar		45-60 lb	Samples 81-in.^{2} area to a depth of less than 12 in. Ineffective in hard clay.
Drag bucket		Varies	Skims an irregular slice of sediment surface. Available in assorted sizes and shapes.
Phleger tube (gravity corer)		Variable: 17-77 lb; fixed in excess of 90 lb	Shallow core samples may be obtained by self-weight penetration and/or pushing from boat. Depth of penetration dependent on weight and sediment texture.
Reineck box sampler		1650 lb	Samples 91.3-in.^{2} to a depth of 17.6 in.

grab sampler is a device that usually triggers after free-falling and is used to retrieve surficial sediments. The difficulty with this approach is that the depth of sediments penetrated by the sampler may vary, depending on the weight and shape of the sampler, the sediment texture and density, the height of free-fall, and the angle of impact.

(2) Maintenance projects. One situation where the selection between grabs and corers may not be critical is in the evaluation of dredging activities in maintenance work projects. In these areas, the sediments that have accumulated since the last maintenance project are generally subjected to continual reworking due to marine traffic. The net effect of this activity homogenizes the sediments that have accumulated. Because maintenance dredging is concerned with the removal of accumulated sediments rather than deepening or creating new channels, grab samplers should be sufficient in these situations.

(3) New work. When the project being evaluated includes either deepening of an older channel or creation of a new channel, it is recommended that cores be collected. Also, when possible, the cores should be taken to a depth equivalent to the proposed project depth.

h. Sample Preservation. The importance of sample preservation between time of collection and time of analysis cannot be overemphasized. The purpose of collecting samples is to gain an understanding of the source (point of origin) of the sample; any changes in sample composition can invalidate conclusions regarding the source of the samples. To phrase it another way, results based on deteriorated samples negate all efforts and costs expended to obtain good examples.

(1) The most efficient way to ensure a lack of sample deterioration is to analyze samples immediately. However, this is usually not practical and some method must be relied upon to extend the integrity of the sample until the analyses can be completed. In taking this approach, it must be remembered that complete stabilization is not possible and no single preservation technique is applicable to all parameters.

(2) Preservation is intended to retard biological action, hydrolysis, and/or oxidation of chemical constituents and reduce volatility of constituents. Refrigeration in an airtight container is the only acceptable method to preserve sediments for bioassays. The elapsed time between sample collection and sample preservation must be kept to an absolute minimum.

(3) The effects of transportation and preservation of sediment samples have not been fully evaluated. However, it is suggested that sediment samples be sealed in airtight glass containers to preserve the anaerobic integrity of the sample and maintain the solid phase-liquid phase equilibrium.

5-4. Data Analysis, Interpretation, and Presentation of Results.

a. Data Analysis Plan. A plan for data analysis should be formulated at the experimental design step since the type of analysis selected will dictate the number and frequency of samples or measurements which must be taken. Several techniques are available for data analysis.

(1) Qualitative analysis. Results of qualitative analyses are generally prose statements based on visual observations, inductive reasoning, and perhaps a few measurements: for example, "Disposal of dredged material from site 2 off Brown's Point has caused local increases in turbidity. A turbidity plume has been observed extending approximately 600 feet to the southwest during three different disposal operations." The value of qualitative analysis can be substantial if it can be established that other factors which could affect results were controlled, constant, or not applicable. The following addition to the previous statement considerably enhances its usefulness. "No turbidity plumes have been observed in this area during other disposal operations. Investigation of other factors that could have caused a turbidity plume of this size has ruled out all other reasonable explanations for its existence."

(2) Maps and graphical analysis. Patterns inherent in data can often be revealed by mapping or graphing the data. Maps are used to show two- and three-dimensional spatial patterns, whereas graphical approaches are most useful for showing temporal relationships or variations with a single dimension such as distance or depth. In general, variables can be divided into two types--continuous and discontinuous (or discrete)--and appropriate map and graphical techniques vary, depending on how variables are measured and distributed.

(a) Maps. Phenomena to be mapped may be distributed in a continuous or discrete manner. Discrete distributions are composed of individual elements that are countable or measurable (such as people, fish, or trees), whereas with continuous distributions there are no recognizable individuals (e.g., air temperature or rainfall). Symbols such as dots may be used to map discrete distributions to reveal patterns. Discrete data are often converted into densities by dividing counts of individuals (frequencies) by the areas of the spatial observation units. The results (people per square mile, biomass per square feet, etc.) may be plotted on maps. Patterns are often enhanced by grouping all values into five or six classes and mapping each class with a separate tone or color. Data representing continuous distribution are usually plotted and contoured to reveal patterns (Figure 5-5).

(b) Graphs. Graphic techniques specialized for certain disciplines or types of data are too numerous to describe. As with maps, however, graphic techniques vary with the type of data. Discrete data are often graphed as frequency histograms (or by graphs), with frequencies on the vertical axis and classes or categories on the horizontal axis. Continuous data are usually plotted as curves, with the spatial or temporal dimension on the X-axis and the values of the variables on the Y-axis. Logarithmic scales are often used when the data to be graphed vary over more than one order of magnitude. Patterns or trends in irregular curves may be more evident if the data are smoothed with a moving average or by fitting generalized mathematical functions to the plotted points. (Schmid and Schmid (1979) provides a thorough review of graphs and charts; Tukey (1977) provides a discussion of graphical smoothing techniques.)

(c) Complex graphics. More complex maps and graphs such as three-dimensional contour plots, trend surfaces, and perspective plots are also useful, but more difficult to comprehend. Various map and geographical options are available as part of most data management systems.

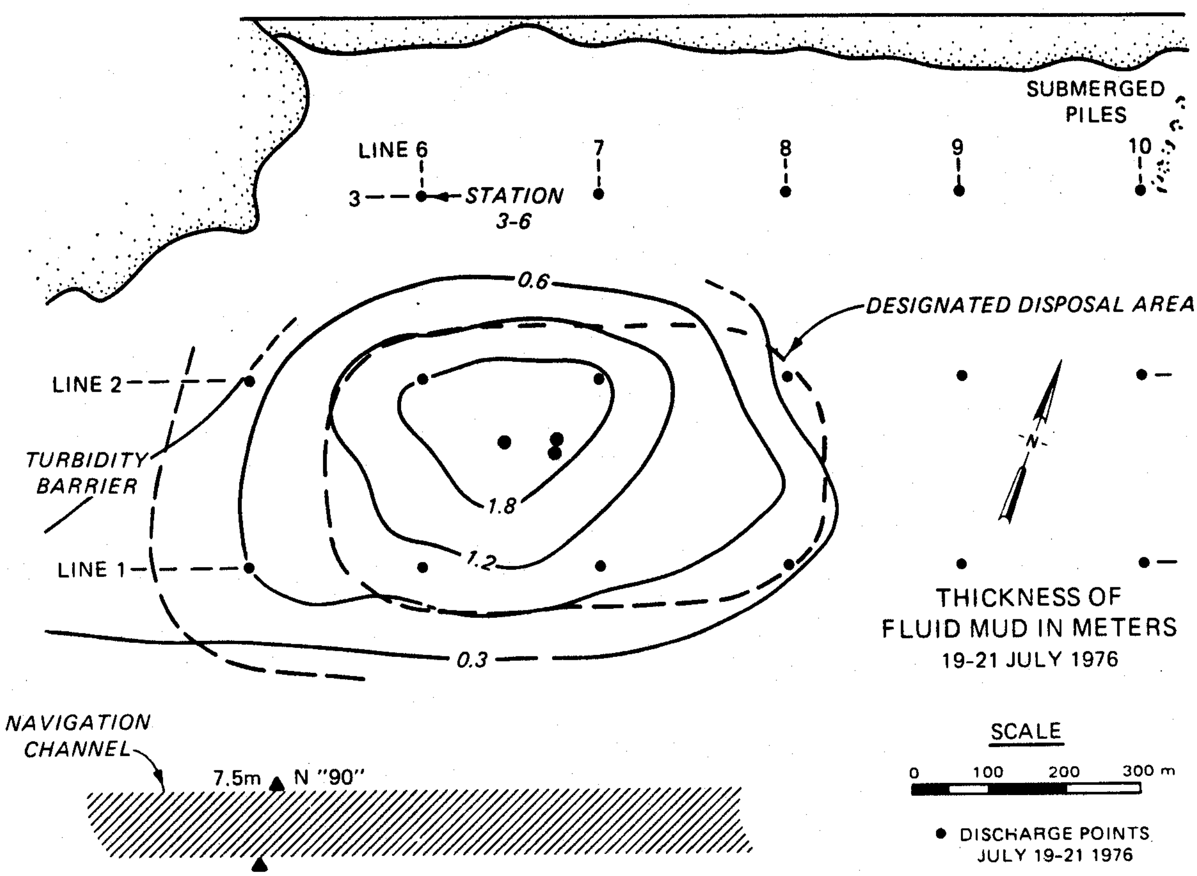


Figure 5-5. Example of continuous distribution displayed by contour map. Contours depict horizontal distribution of fluid mud thickness during open-water dredged material disposal (compiled from acoustic measurements)

(d) Common errors. When using maps and graphic techniques, one must be careful not to draw conclusions that implicitly depend on interpolation between data points (Figure 5-6) or extrapolation beyond the range of the data (Figure 5-7), unless such interpolation or extrapolation can be justified. A choice of scales or coordinate axes that unduly exaggerate or minimize point scatter or differences should be avoided.

(3) Statistical analysis. Statistical analysis can be used to summarize or describe complex data bases. Statistics can also be used as a formal decisionmaking tool to decide whether measured temporal or spatial differences between samples are real or whether they may be the result of sampling variability. Commercially available data management systems (paragraph 5-5) have options for computing and displaying several types of statistics.

(a) Descriptive statistics. Large amounts of data can be summarized by calculating statistics such as measures of central tendency (mean, median, and mode) and dispersion (standard deviation and range). Statistics can be used to compare sets of data to determine if differences exist among them and, if so, whether the differences are meaningful.

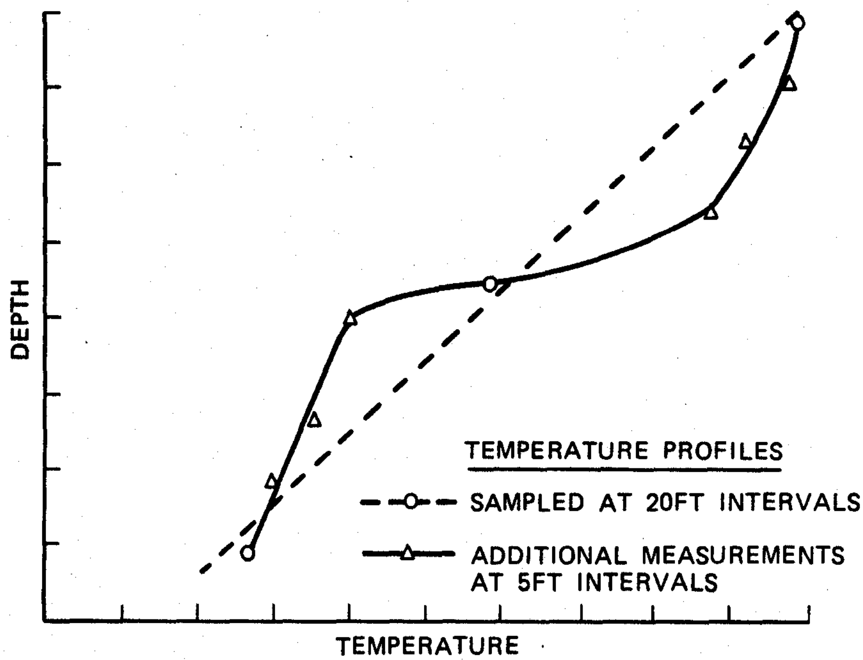


Figure 5-6. Error caused by improper interpolation. Depth-temperature relationship appears linear when sampled at 20-foot intervals, but nonlinear when sampled at 5-foot intervals

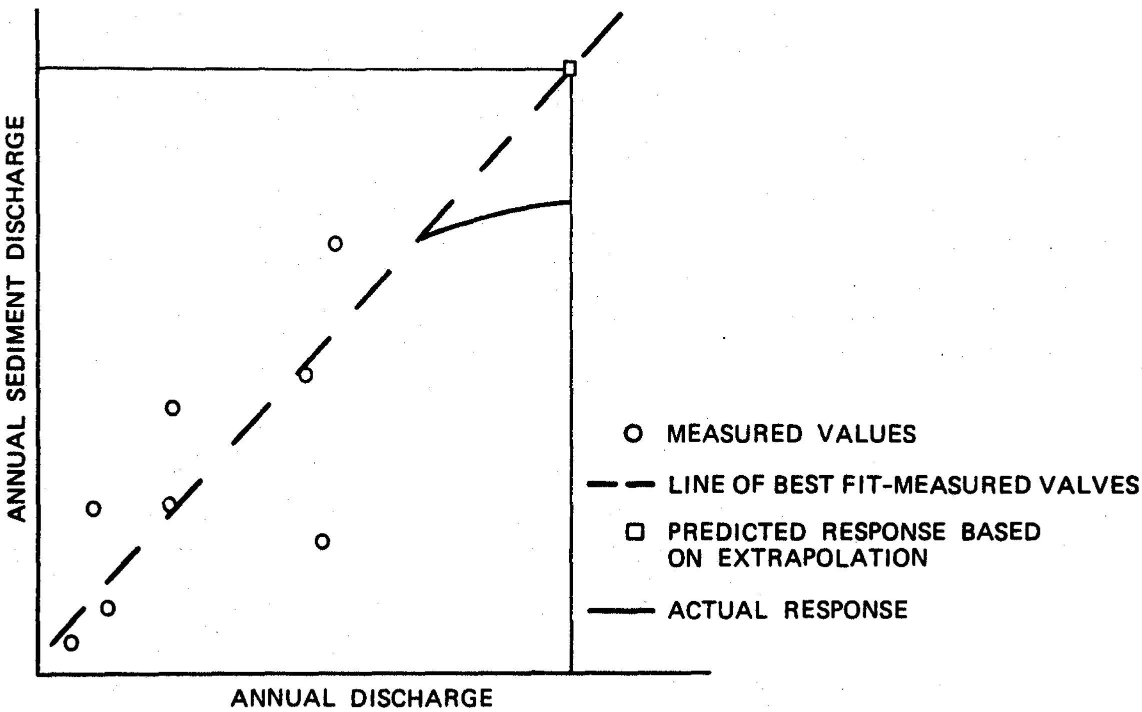


Figure 5-7. Error caused by improper extrapolation

(b) Hypothesis testing. Formulas are available for determining if observed differences between sample data sets are real, or if they may have occurred by chance due to the size or selection of samples used in calculating the statistics. These techniques are called significance tests, and theories and formulas for their use are given in basic texts on statistics and experimental design. Users should be cautioned, however, that observed differences may be statistically significant and yet not be very meaningful. Special techniques have been developed for analysis of biological data, particularly benthic biota data. (Pequegnat et al. (1981) and Sokal and Rohlf (1960) review several of these techniques.)

(c) Correlation and regression. Relationships among variables may be explored using correlation and regression analysis. For example, the relationship between the density of a certain benthic species and certain physical (velocity, temperature, sediment grain size) and chemical (DO) parameters might be explored using correlation and regression. Basic theory and formulas for correlation and regression are given in statistics texts. It is important to understand that high correlations do not imply cause-and-effect relationships. Kenney (1982) discusses spurious self-correlations which result when another variable that is a ratio, product, sum, or difference is correlated with another variable that has a common term. Correlation and regression with several variables should not be attempted without a good understanding of the basic assumptions that must be met in order to use the techniques effectively. Misuse of regression and correlation is discussed in most multivariate statistical texts. Mather (1976) presents a thorough discussion of the basic assumptions of multiple correlation and regression and of some of the mathematical and data constraints that influence results.

(d) Advanced statistical techniques. Most data management systems contain programs for a variety of advanced statistical techniques which may be useful for describing patterns and explaining complex relationships among many variables. Use of these analytical techniques should generally be avoided except by individuals with sufficient training to understand the statistical and mathematical constraints to proper use of the techniques.

b. Data Interpretation.

(1) Editing. Database checking and editing should precede analysis. Extreme errors may be detected by computer programs that check for boundary conditions and ensure data values are within reasonable limits. Quality work requires human judgment. Simple computer-generated plots of the raw data should be generated and examined for unreasonable values, extreme values, trends, and outlines. More detailed editing should include checking all or random samples of the computer database values against data sheets from the lab or field.

(2) Analysis. The next step in data interpretation is to ensure that the assumptions on which the data analysis plan is based are still valid. New information or failure to collect all the data required by the original analysis plan may necessitate modification. Data analysis should then proceed according to plan, and a decision should be made to accept or reject the hypothesis. Following this step, an effort should be made to identify additional quantitative or qualitative conclusions that may be warranted, and additional

hypotheses that may be tested using the database. If resources permit, this additional analysis may be completed prior to formulation of final conclusions. Final conclusions should not be limited to acceptance or rejection of hypotheses, but should extend to clear, verbal expression of the implications of the observed results. Decisionmakers who are not technical specialists may fail to grasp these implications unless they are clearly communicated.

c. Presentation of Results. Results should be presented in a format appropriate for the majority of the intended audience. Presentation of large volumes of numerical data is generally undesirable; however, provision should be made for long-term data storage and retrieval. Graphical displays can be effective if the complexity of the plots is not too great for the selected audience. A few representative, simplified plots which serve as examples of major findings or conclusions are generally best.

5-5. Database Management.

a. General. The success of any study effort, especially one involving multiple investigators and disciplines, will be heavily influenced by the quality of plans to deal with: (1) data management, storage, and retrieval of information, and (2) the compatibility between data units and formats and programs for data reduction and analysis. A carefully designed plan for handling information will guarantee that once field and laboratory work is completed, information will be readily available for examination and analysis and in a form useful to management.

b. Data Management Plan. A data management plan detailing procedures for handling data storage and retrieval should be formulated at the outset of an environmental study. The simplest type of database contains only data developed for a single study. A more cost-efficient approach is to develop a single database for all environmental studies within the Corps field office with standardization of measurement and reporting procedures to ensure internal compatibility. Once the database is developed, the database manager should be conservative in decisions about changes in procedures or data units and should permit such changes only where useful information benefits can clearly be identified.

c. Database Incompatibility. Frequently, various studies associated with one project will be conducted by several different agencies or contractors. It is also not unusual that during the course of a project, the same scope of work might be performed by different contractors at different times. Besides reinforcing the need for standardization discussed above, the probability of a multiple-contractor operation stimulates logistical questions about information storage, retrieval, and analysis. The Federal agencies, academic institutions, and consulting companies who ordinarily conduct the work will usually have their own computer support. This situation could lead to the formation of several different data files existing in different computers.

Database incompatibilities will create problems for those who have responsibility for synthesizing the products of multiple investigators. Also, a new contractor performing a scope of work previously performed by a different contractor will encounter problems when attempting comparative analyses involving the two sets of observations. Two solutions to this problem are possible.

(1) Central computer. This solution would require all contractors to use the same computer; the field office would also need access to data files stored in this computer. This solution is not recommended however because it deprives the contractor of computer services and programs he is most familiar with and, therefore, could use most efficiently.

(2) Individual computers. This solution, which is the recommended approach, would permit each contractor the computer of his choice. However, each contractor must be required to transmit information to the Corps field office in a machine-readable form compatible with the Corps' computer and in standardized format and units. As noted above, any changes in format, units, or approach should be carefully considered because those changes would have system-wide impacts.

5-6. Water Quality and Biological Data Collection Considerations. This paragraph outlines the considerations involved in data collection on the aquatic and biological aspects of deep-draft navigation projects.

a. Water Quality.

(1) Regulations. Section 103 of MPRSA specifies that all proposed operations involving the transportation and dumping of dredged material into ocean waters be evaluated to determine the potential environmental impact of such activities. This must be done by the Secretary of the Army and the Administrator of the EPA acting cooperatively through the District Engineer and Regional Administrator. Environmental evaluations must be in accordance with criteria published by EPA (40 CFR 220). Section 404(b) of the Clean Water Act (CWA) specifies that any proposed discharge of dredged or fill material into navigable waters must be evaluated through the use of EPA guidelines developed jointly with the Secretary of the Army. The District Engineer must make the evaluation in accordance with guidelines published by EPA (40 CFR 230).

(2) Environmental consequences.

(a) Ecological impacts. Ecological impacts of the discharge of dredged or fill material can be divided into two main categories: physical effects and chemical-biological interactive effects. Physical effects are often straightforward, and evaluation may often be made (without laboratory tests) by examining the character of the dredged or fill material proposed for discharge and the sediments of the discharge area with particular emphasis on the principles delineated in EPA regulations. However, the chemical-biological interactive effects resulting from the discharge of dredged or fill material are usually difficult to predict.

(b) Approach. Often there are concerns over the potential environmental consequences of discharge operations. The principal concern regarding open-water discharge of dredged or fill material that contains chemical contaminants relates to the potential effects on the water column and benthic communities due to the presence of the contaminants. These concerns can be addressed by the following approaches:

1 Release of chemical contaminants from the sediment to the water column may be simulated by use of an elutriate test.

2 To the extent permitted by the state of the art, expected effects such as toxicity, simulation, inhibition, or bioaccumulation may be estimated by appropriate bioassays and biological assessments.

3 An evaluation or comparison of proposed disposal sites and an inventory of sediment and water constituents may be evaluated by the use, where appropriate, of total sediment analysis or bioevaluation. Considering the potential complexity of involved ecosystems, no single test can be used to evaluate all effects of proposed discharges of dredged or fill material. Consequently, the guidelines and criteria published by EPA provide a general protocol to be used in the technical evaluation of the proposed activities. Each procedure used should provide relevant information about the proposed discharge activity. There are, however, limitations associated with the use of the results obtained with each procedure, and no one procedure should arbitrarily be relied upon to the exclusion of the others. For example, total sediment analysis results cannot be used to assess water quality effects, and elutriate test results cannot be used to assess effects on benthic organisms. Also, when it becomes necessary to perform bioassays as part of the evaluation procedure, experimental conditions should reflect the exposure times and exposure concentrations that would be expected in the field based on the dilution and dispersion at the proposed disposal site. Each of these limitations must be considered when selecting, conducting, and evaluating the results of the procedures required by EPA regulations.

(3) Procedural guidance.

(a) General. The EPA, in conjunction with the Corps of Engineers, has published a comprehensive procedures manual (US Environmental Protection Agency/US Army Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material 1977) that contains summaries and descriptions of tests, definitions, sample collection and preservation procedures, analytical procedures, calculations, and references required for detailed water quality evaluations in accordance with EPA requirements. The purpose of this manual is to provide a state-of-the-art summary on sampling, preservation, and analysis of water and dredged and fill material. The information compiled and presented in this manual consists of three major sections:

1 A discussion of rationale for project or study managers.

2 A step-by-step protocol for sample collection and handling and each test procedure.

3 A listing of analytical techniques, including sample pretreatment procedures.

It is expected that this manual will receive wide use as an aid in the regulatory process.

(b) CWA, Section 404(b). Interim guidance for implementing Section 404(b) of the CWA was published in 1976 (US Army Engineer Waterways Experiment Station 1976). It should be viewed as a second generation in the continuing process of procedure development, refinement, and evaluation of the CWA requirements. Thus, the interim guidance is intermediate between the EPA regulations and analytical compendiums such as Standard Methods for the Examination of Water and Wastewater including bottom sediments and sludges (American Public Health Association 1975), the American Society of Testing and Materials (ASTM) manual (American Society for Testing and Materials 1976), and the EPA manual (US Environmental Protection Agency 1979).

(c) MPRSA, Section 103. The primary intent of Section 103 of the MPRSA (US House of Representatives, Committee on Public Works 1973) is to regulate and limit the adverse ecological effects of ocean dumping. Consequently, the EPA-implementing regulation emphasizes evaluative techniques such as bioassays and bioassessments, which provide direct estimations of the potential for environmental impact. To properly conduct the required evaluation requires considerable expertise in conducting biological evaluations. In addition, significant continuing effort and expense are entailed in collecting and culturing sufficient stocks of all the necessary species of organisms and maintaining them in good condition in the laboratory to use whenever an evaluation must be conducted. Consequently, an ocean dumping manual has been published jointly by the EPA and the Corps pursuant to the Ocean Dumping Act (US Environmental Protection Agency/US Army Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material 1977). The ocean dumping manual represents a multidisciplinary effort of both agencies to develop procedurally sound, routinely implementable guidance for complying with the technical requirements of EPA regulations. The procedures given in the manual are applicable to evaluation of the potential ecological effects of dumping from hopper dredges, barges, and scows. The EPA requirements are discussed, and detailed guidance is provided on sediment and water sample collection, preparation, and preservation; chemical analysis of the liquid phase; bioassays of liquid, suspended particulate, and solid phases; estimation of bioaccumulation potential; and estimation of initial mixing. Even though the manual was developed for the ocean dumping program, the approaches have broad application to all aquatic systems for water quality evaluation. A companion quality assurance and quality control manual (Lang et al. 1981) has been developed to aid agencies in giving clear and concise guidance to contractors conducting ecological evaluations. These manuals, used in conjunction with those identified in the previous paragraph, provide a powerful set of tools for use in water quality evaluations.

(d) Data collection and analyses. The collection and preparation of water and dredged material samples for testing and evaluation are the most important factors leading to an evaluation of the impact of dredging and dredged material discharge upon the aquatic environment. Samples that are improperly collected, preserved, or prepared will invalidate any testing results and lead to erroneous conclusions regarding the potential impact of the proposed discharge. Attention must therefore be given to all phases of water and sediment sampling, storage, preparation, and analysis. The procedures described in the referenced manuals specify the apparatus and procedures to use for sampling water and dredged material and for preparing the water and dredged material for chemical analyses and bioassay procedures.

b. Altered Circulation Due to Changes in Geometry. Water quality effects may sometimes be inferred from effects on hydrodynamics and salinity, as outlined in paragraph 3-1. The necessity and design of water quality sampling for the application of numerical modeling are highly dependent upon the selected methodology, as discussed in Appendix C. Methods of sample collection, preservation, and analyses published by the American Public Health Association (1975) and EPA (USEPA 1979) should be used.

c. Biological Data.

(1) Evaluative techniques such as bioassays and bioassessments provide direct estimations of the potential for environmental impact due to contaminated sediments. However, as discussed, such evaluations require considerable expertise and significant continuing effort and expense; for these reasons, obtaining the services of different groups to conduct each evaluation would be impractical. Thus, it is highly recommended that a few groups that have demonstrated bioassay capability be selected, with each group conducting evaluations for a number of permit applications. This will enable these groups to develop adequate culturing and maintenance capabilities and the expertise and familiarity with the procedures required to implement them properly and provide the most reliable results at the least cost per evaluation.

(2) It should be recognized that dredged material bioassays cannot be considered precise predictors of environmental effects. They must be regarded as quantitative estimators of those effects, making interpretation somewhat subjective. In order to avoid adding more uncertainty to their interpretation, most dredged material bioassays use mortality as an end point. The significance of this response to the individuals involved is clear; it remains impossible to predict the ecological consequences of the death of a given percent of the local population of a particular species. For example, there is presently no basis for estimating whether the loss at the disposal site of 10 percent of a particular crustacean species would have inconsequential or major ecological effects.

(3) The suspended particulate phase of dredged material may be evaluated for potential environmental impact only by use of bioassays. No chemical procedure has yet been devised that will determine the amount of environmentally active contaminants present in the suspended particulate phase of dredged material. Therefore, bioassays are used to evaluate directly the potential for biological impacts due to both the physical presence of suspended particles and to any biologically active contaminants associated with the particulates and/or the dissolved fraction.

(4) It is generally accepted that the greatest potential for environmental impact from a given dredged material lies in the solid phase. This is because it is not mixed and dispersed as rapidly or as greatly as suspended phases. No chemical procedures exist that will determine the environmental activity of any contaminants or combination of contaminants present in the solid phase of dredged material. Therefore, animals are used in a bioassay to

provide a measurement of environmental activity of the chemicals found in the material.

(5) Biological evaluations of dredged material often include an assessment of the potential for contaminants from the dredged material to be bioaccumulated in the tissues of organisms. This is intended to assess the potential for the long-term accumulation of toxins in the food web to levels that might be harmful to the ultimate consumer, which is often man, without killing the intermediate organisms. In order to use bioaccumulation data, it is necessary to predict whether there will be a cause-and-effect relationship between the animals' presence in the dredged material and a meaningful elevation of body burdens of contaminants above those of similar animals not in the dredged material.

(6) Since concern about bioaccumulation is focused on the possibility of gradual uptake over long exposure times, primary attention is usually given to the solid phase that is deposited on the bottom. A variety of laboratory research methods for measuring bioaccumulation are presently undergoing modification and evaluation as regulatory tools. All such methods require one month or more for completion and provide no quantitative method for considering field conditions, such as mixing, in the interpretation of the results. Field sampling programs overcome the latter difficulty since the animals are exposed to the conditions of mixing and sediment transport actually occurring at the disposal site in question. The former difficulty is also overcome if organisms already living at the disposal site are used in the bioaccumulation studies. The use of this approach for predictive purposes is technically valid only where there exists a true historical precedent for the proposed operation being evaluated. That is, it can be used only in the case of maintenance dredging where the quality of the sediment to be dredged is considered not to have deteriorated or become more contaminated since the last dredging and disposal operation. In addition, the disposal must be proposed for the site at which the dredged material in question has been previously disposed or for a site of similar sediment type supporting a similar biological community.

(7) Considering these limiting conditions, it is possible to assess bioaccumulation by animals that have spent major portions of their life in or on a sediment very similar to the sediment in question, under the physical and chemical conditions actually occurring at the disposal site. Caged animals of suitable species may also be placed at appropriate stations in and around the disposal site, but this will require a substantial exposure time before analysis.

(8) Under the above conditions, a field assessment provides the most useful information because the animals have been exposed to the sediment under natural conditions for longer periods than are now generally practical in the laboratory. To the extent that source control has prevented increased input of contaminants, it will generally be true that sediment quality at dredging sites will not be lower than at the time of previous dredging and disposal operations. Therefore, since the same disposal site is traditionally used repeatedly for each dredging site, a valid historical precedent probably exists for most disposal operations.

(9) The environmental interpretation of bioaccumulation data is even more difficult than for bioassays because in most cases it is impossible to quantify either the ecological consequences of a given tissue concentration of a constituent that is bioaccumulated or the consequences of that body burden to the animal whose tissues contain it. Almost without exception in the aquatic environment, there is no technical basis for establishing, for example, the tissue concentration of zinc in a species of crustacean that would be detrimental to that organism, not to mention the impossibility of estimating the effect of that organism's body burden on a predator. Therefore, in order to ensure environmental safety, interpretative guidance often assumes that any statistically significant bioaccumulation relative to animals not in dredged material, but living in material of similar sedimentological character, is potentially undesirable. The evaluation of experimental results using this approach requires the user to recognize the fact that a statistically significant difference cannot be presumed to predict the occurrence of an ecologically important impact.

(10) In bioassays, marine organisms are used, in a sense, as analytical instruments for determining the environmentally active portions of any contaminants present. Lack of effect in bioassays and bioaccumulation studies is taken to mean that contaminants are absent or present only in amounts and/or forms that are not environmentally active. When effects do occur in dredged material bioassays, it is not possible within the present state of knowledge to determine which constituent(s) caused the observed effects. Indeed, if an adverse effect occurs, it matters little from a regulatory viewpoint whether that effect is due to the physical presence of the sediment or is due to some chemical constituent(s) associated with the sediment carried beyond the site. Therefore, it is important to realize that this benthic bioassay measures the total impact of the dredged material--that impact may be due to an unrecognized pollutant or to the synergistic effects of many pollutants, none of which may have an exceptionally elevated concentration. At the present technical state of the art, it is not possible to determine by any known chemical analysis which pollutant(s) may be the causative agent(s).